Overview of GRETINA Status

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Conference on Nuclear at the Limits

July 26-30, 2004

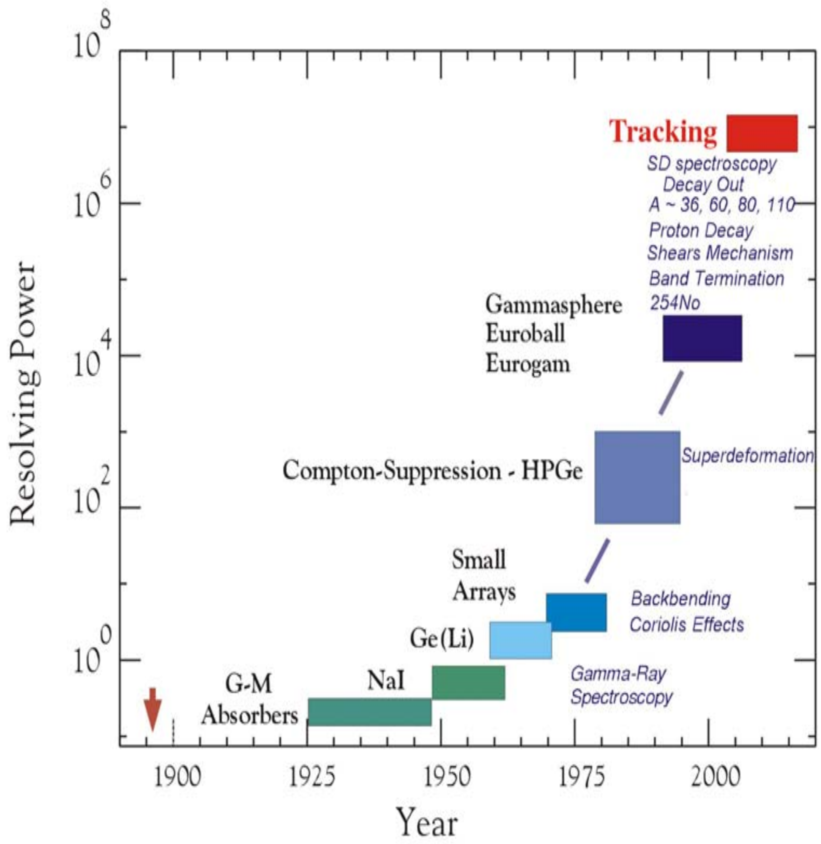
Argonne National Laboratory

Outline

- Principle of gamma ray tracking
- Physics opportunities
- Technical challenges
- Status of project

Gamma-ray Detector

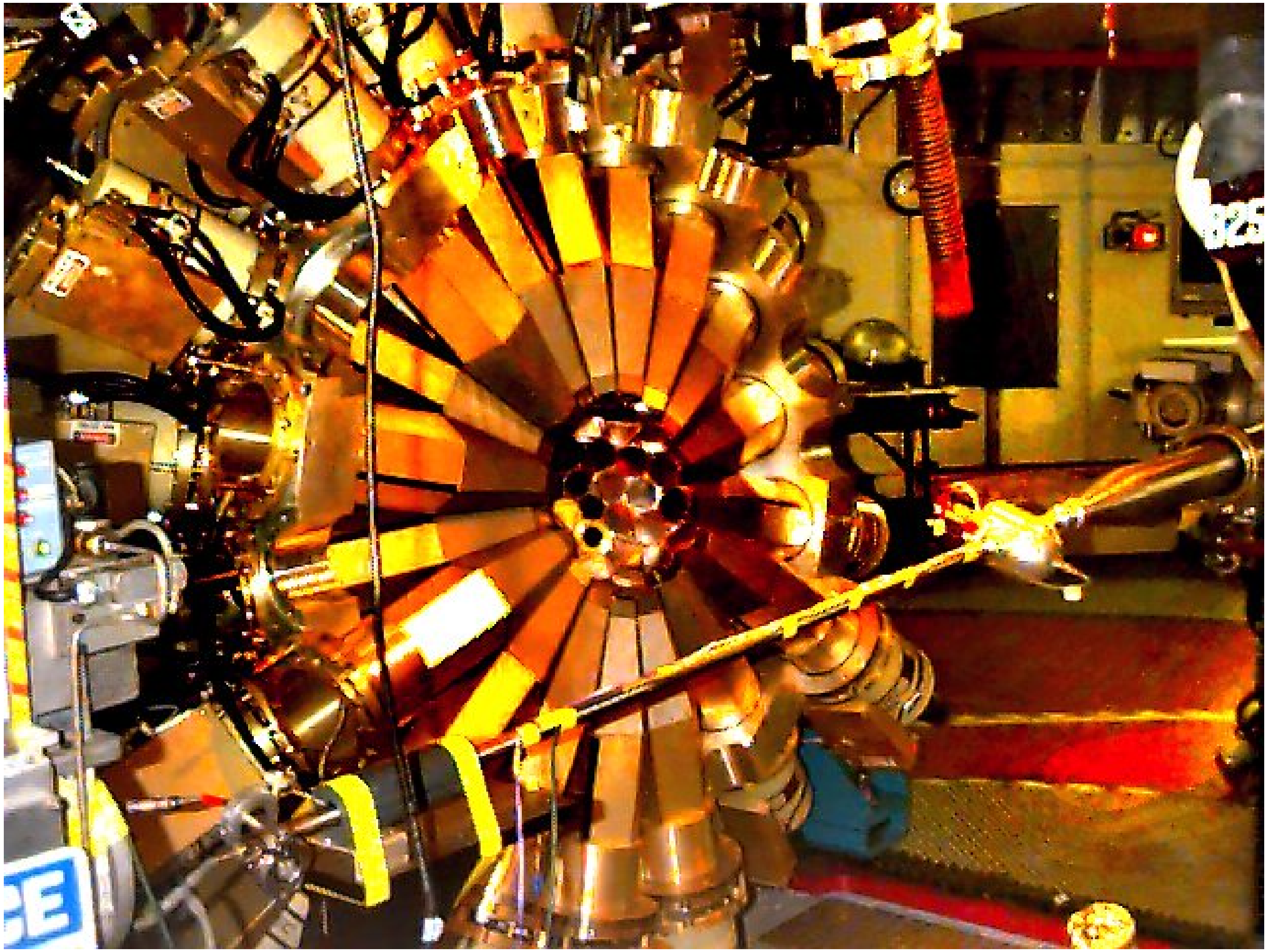
Crucial to Nuclear Physics



- **Advances in detector technology have resulted in new discoveries.**
- **Innovations have improved detector performance.**
  - **Energy resolution**
  - **Efficiency**
  - **Peak-to-total ratio**
  - **Position resolution**
  - **Directional information**
  - **Polarization**
  - **Auxiliary detectors**
- **Tracking is feasible, will provide new opportunities and meet the challenges of new facilities.**

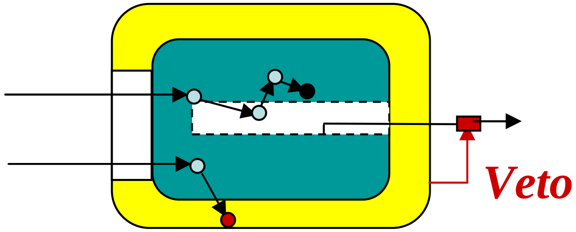
Gammasphere

110 Compton suppressed Ge detectors



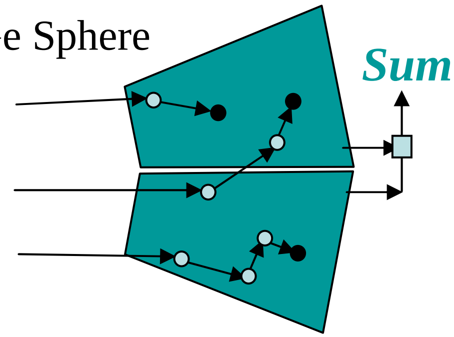
Gamma-ray Tracking Concepts

- Compton Suppressed Ge



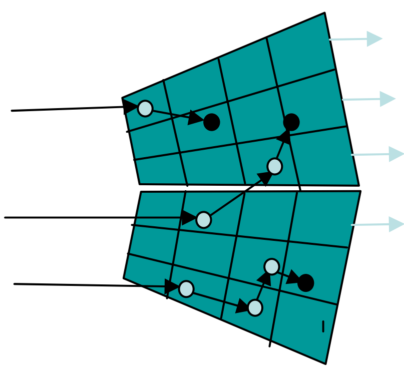
$N_{det} = 100$
Peak efficiency = 0.1
Efficiency limited

- Ge Sphere



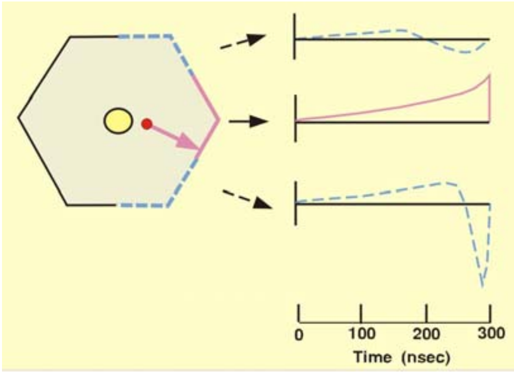
$N_{det} = 1000$ **(summing)**
Peak efficiency = 0.6
Too many detectors

- Gamma Ray Tracking

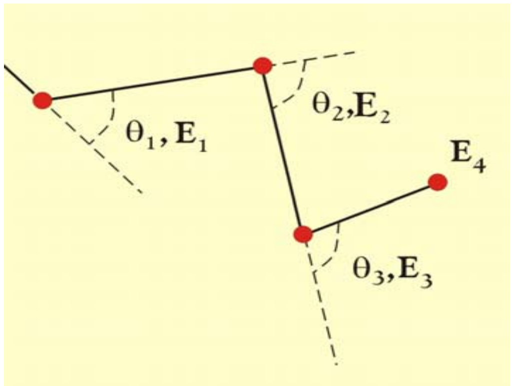


$N_{det} = 100$
Peak efficiency = 0.6
Segmentation

Pulse shape analysis in segments ➔ 3D position



Tracking of photon interaction points ➔ energy, position



Capabilities of GRETA

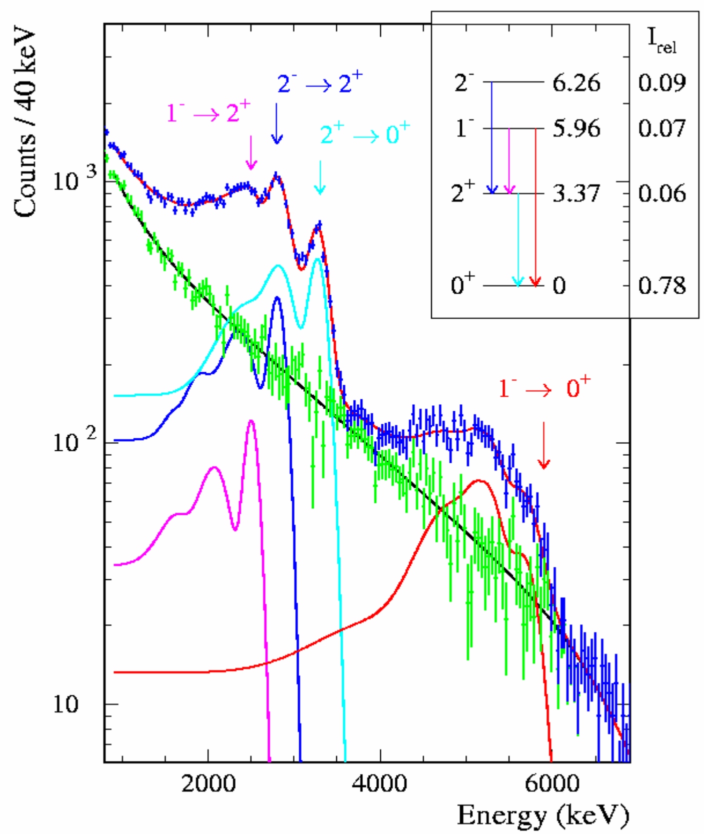
- Resolving power: 10^7 vs. 10^4
  - Cross sections down to ~1 nb
    - Most exotic nuclei
    - Heavy elements (e.g. ^{253,254}No)
    - Drip-line physics
    - High level densities (e.g. chaos)
- Efficiency (high energy) (23% vs. 0.5% at E_γ=15 MeV)
  - Shape of GDR
  - Studies of hypernuclei
- Efficiency (slow beams) (50% vs. 8% at E_γ =1.3 MeV)
  - Fusion evaporation reactions
- Efficiency (fast beams) (50% vs. 0.5% at E_γ =1.3 MeV)
  - Fast-beam spectroscopy with low rates -> RIA
- Angular resolution (0.2° vs. 8°)
  - N-rich exotic beams
    - Coulomb excitation
  - Fragmentation-beam spectroscopy
    - Halos
    - Evolution of shell structure
    - Transfer reactions
- Count rate per crystal (100 kHz vs. 10 kHz)
  - More efficient use of available beam intensity
- Linear polarization
- Background rejection by direction

Physics opportunities of GRETA

- How does nuclear shell structure and collectivity evolve in exotic n-rich nuclei?
- What is the influence on increasing charge on the dynamics and structure for the heaviest nuclei?
- How do the collective degrees of freedom and shell structure evolve as the excitation energy and angular momentum increases?
- What are the characteristics of the Giant Dipole Resonances built on superdeformed states and loosely bound nuclei?

Mapping wave functions of exotic nuclei

■ What are the spectroscopic factors in the wave function of exotic nuclei?



T. Aumann *et al.*, Phys. Rev. Lett. **84** (2000) 35.

Experiment

- Intermediate-energy nucleon knockout
- Thick secondary targets require γ-ray detection to indicate inelastic scattering

Challenges

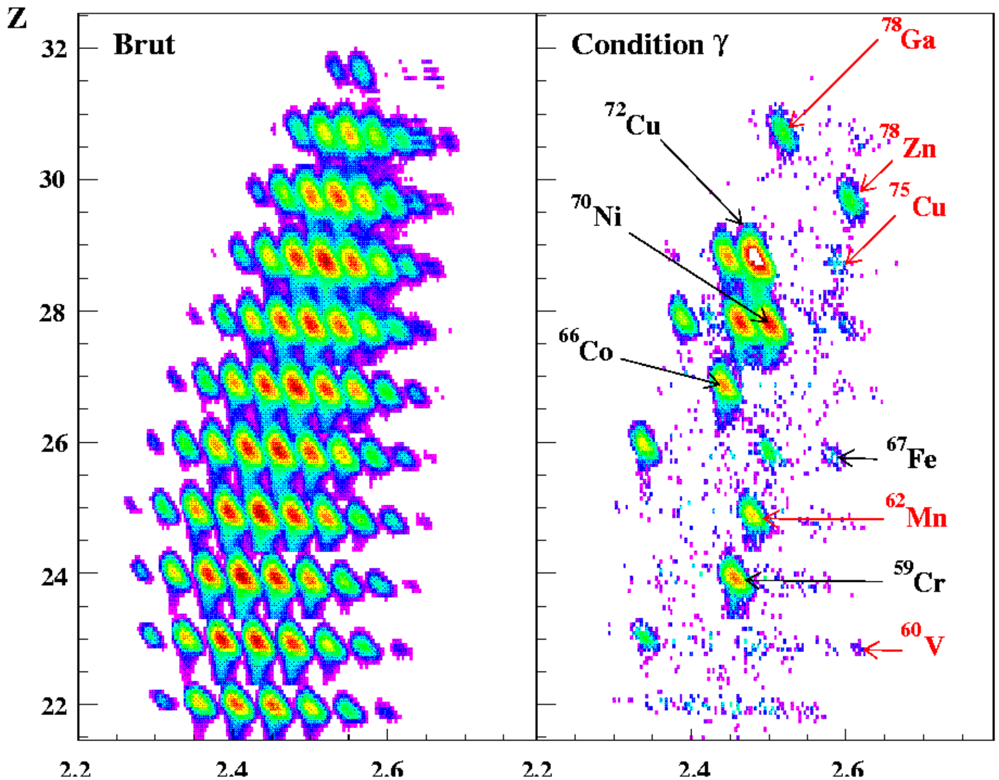
- Need γ-ray emission angle for Doppler-shift reconstruction
- Low beam rate (0.1/s)

The gamma-ray tracking advantage

- Efficiency
- Angular resolution
- Extends reach of NSCL CCF and RIA two neutrons further from stability

Properties of the most exotic nuclei

- What are the properties of the most exotic nuclei?



Experiment

- Beta-decay after implantation
- Bound excited states of daughter
- Clean beta trigger, beta detection >98% efficient

Major challenge

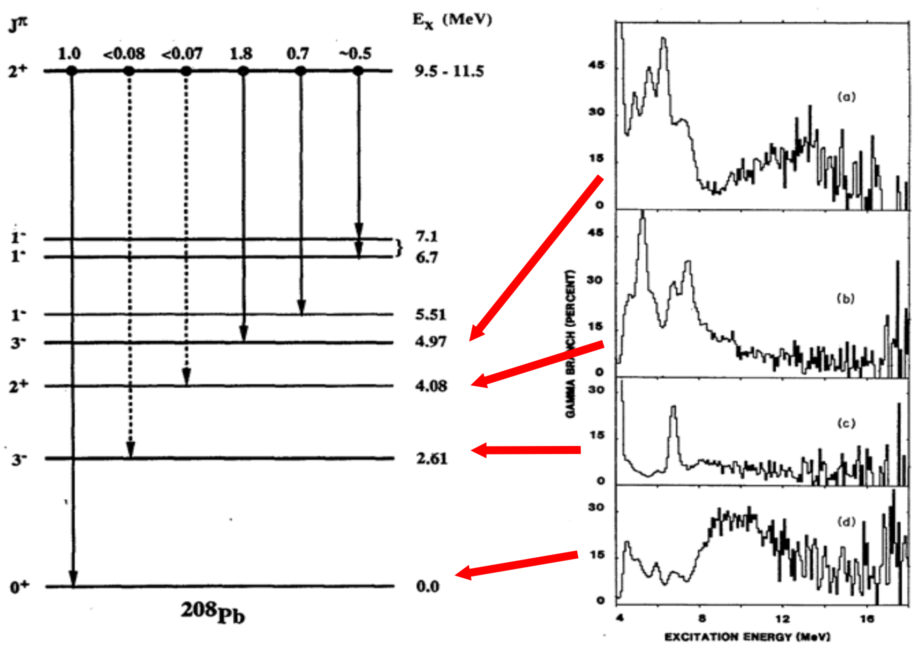
- Minute cross section: 1 atom/week (fb)

The gamma-ray tracking advantage

- Efficiency
- Background rejection by photon direction

Giant resonances built on excited states

■ What is the angular momentum dependence of the giant resonance width?



J.R. Beene et al., Phys. Rev. C ***39*** *(1989) 1307.*

Experiment
- Virtual photon scattering
- Tag on low-energy transitions
- Simultaneously detect high-energy γ-rays

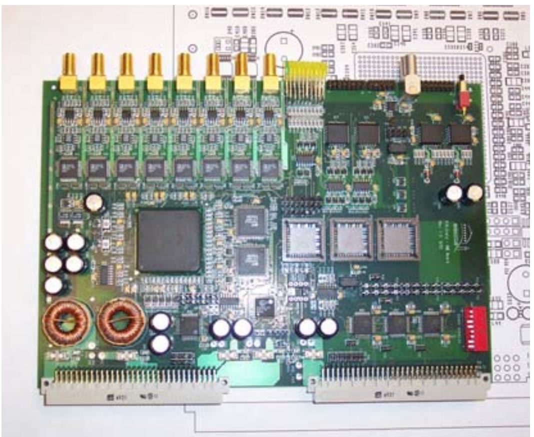
Challenges
- Need γ-ray emission angle for Doppler-shift reconstruction

The gamma-ray tracking advantage
- Efficiency at low and high photon energies
- Angular resolution

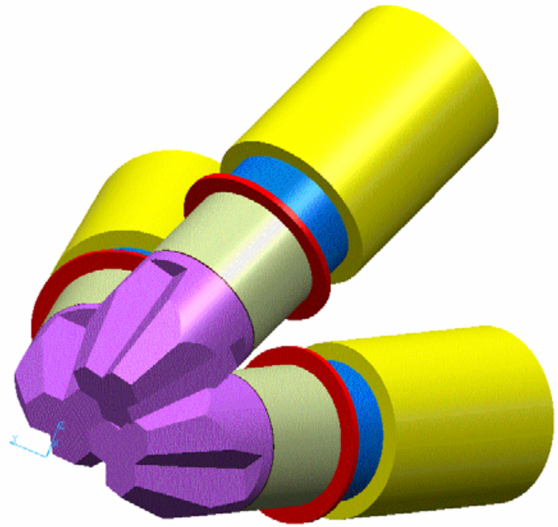
History of γ-ray tracking

- **1994 Conceptual design study**
- **1995 Duke Town meeting (1996 LRP) first discussion**
- **1997 First prototype received and tested**
- **1998 Workshop on GRETA physics (LBNL)**
- **1999 GRETA advisory committee formed**
- **1999 Second prototype received and tested**
- **2000 Workshop on GRETA physics (MSU)**
- **2000 Proposal for a GRETA module cluster submitted and reviewed, prototype funded 2002**
- **2001 National Steering Committee formed**
- **2001 Santa Fe meeting (2002 LRP) presentation and discussion**
- **2001 Workshop on Digital Electronics in Nuclear Physics (ANL)**
- **2001 Workshop on Gamma-ray tracking detectors (Lowell)**
- **2002 Gamma Ray Tracking Coordination Committee review**
- **2003 Proposal for GRETINA -1/4 of 4π (June)**
- **2003 Receive DOE CD0 approval (Aug.)**
- **2004 Receive DOE CD1 approval (Feb.)**

Major subsystems of GRETINA

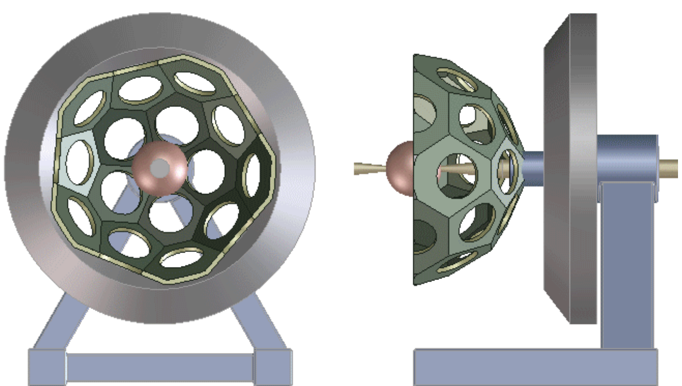


Data acquisition

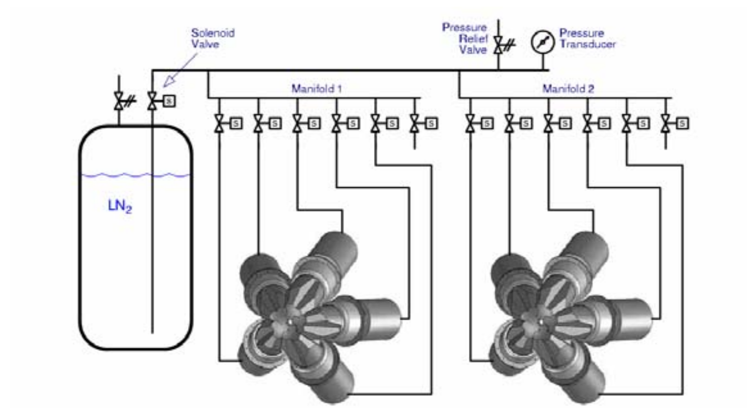


Detector

Computing



Mechanical structure

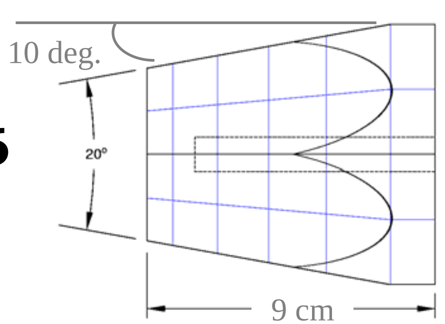


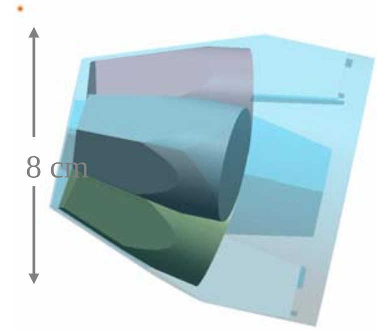
Liquid nitrogen system

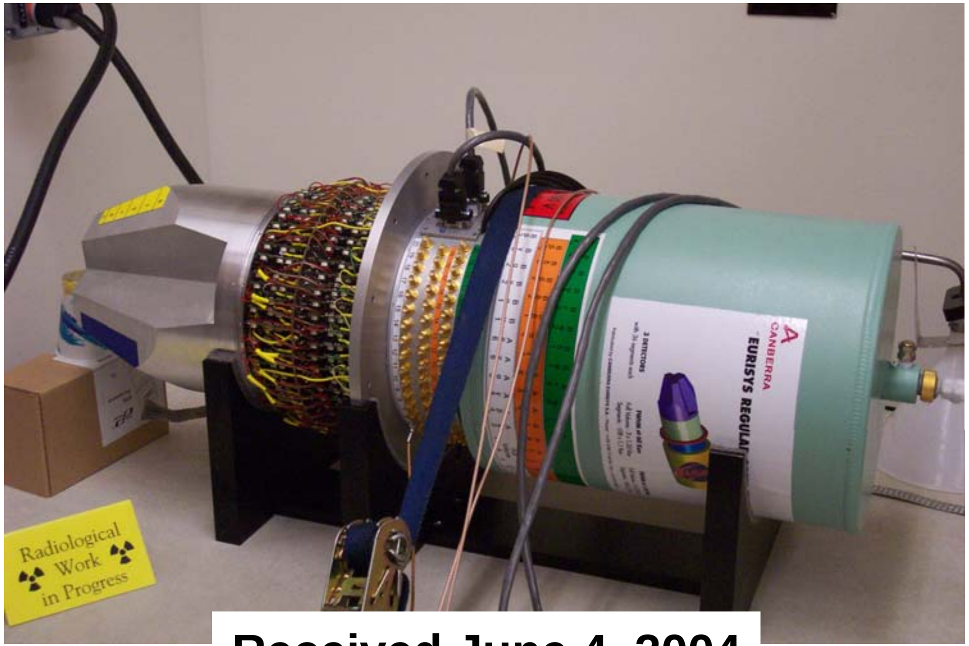
Three-crystal prototype

Building block of GETINA

- Tapered hexagon shape
- Highly segmented $6 \times 6 = 36$
- Close packing of 3 crystals
- 111 channels of signal







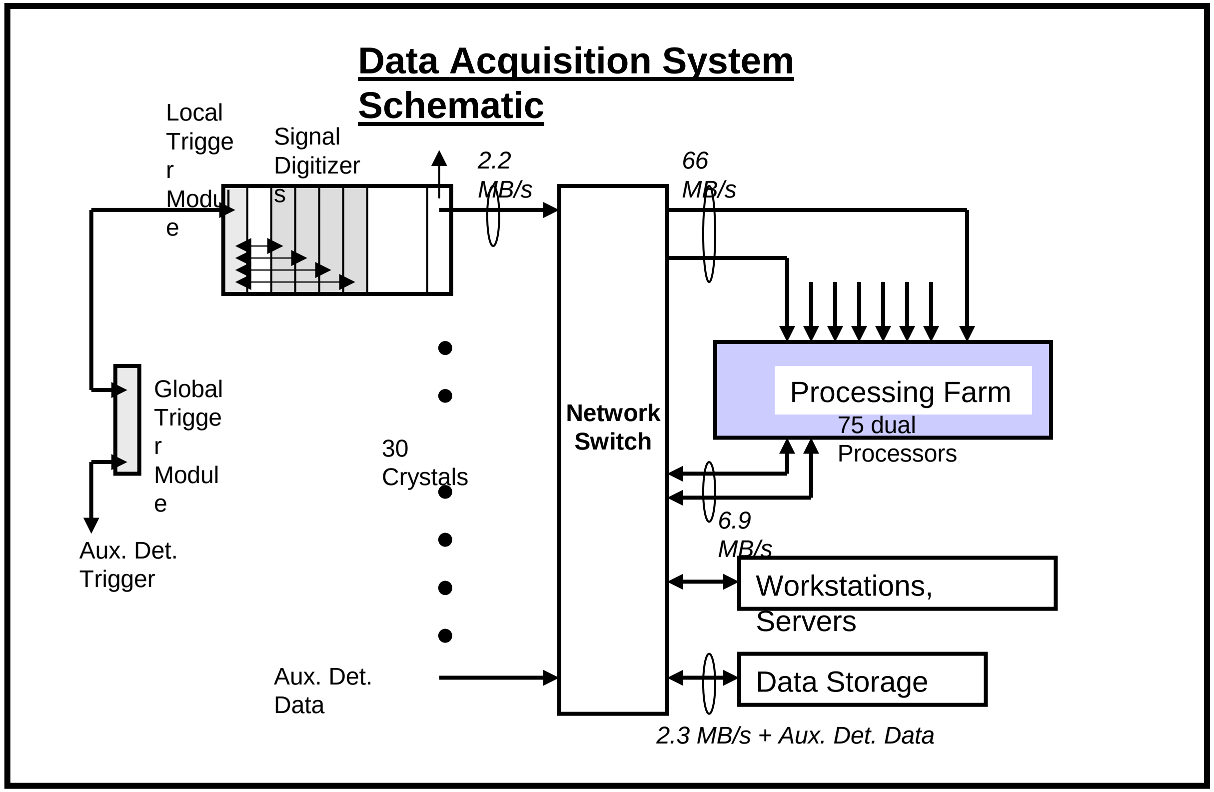
Received June 4, 2004

TESTS

- Mechanical dimension
- Temperature and LN holding time
- Energy resolution
- Pulse shape : scan
- End-to-end test: source and in-beam

Data acquisition system

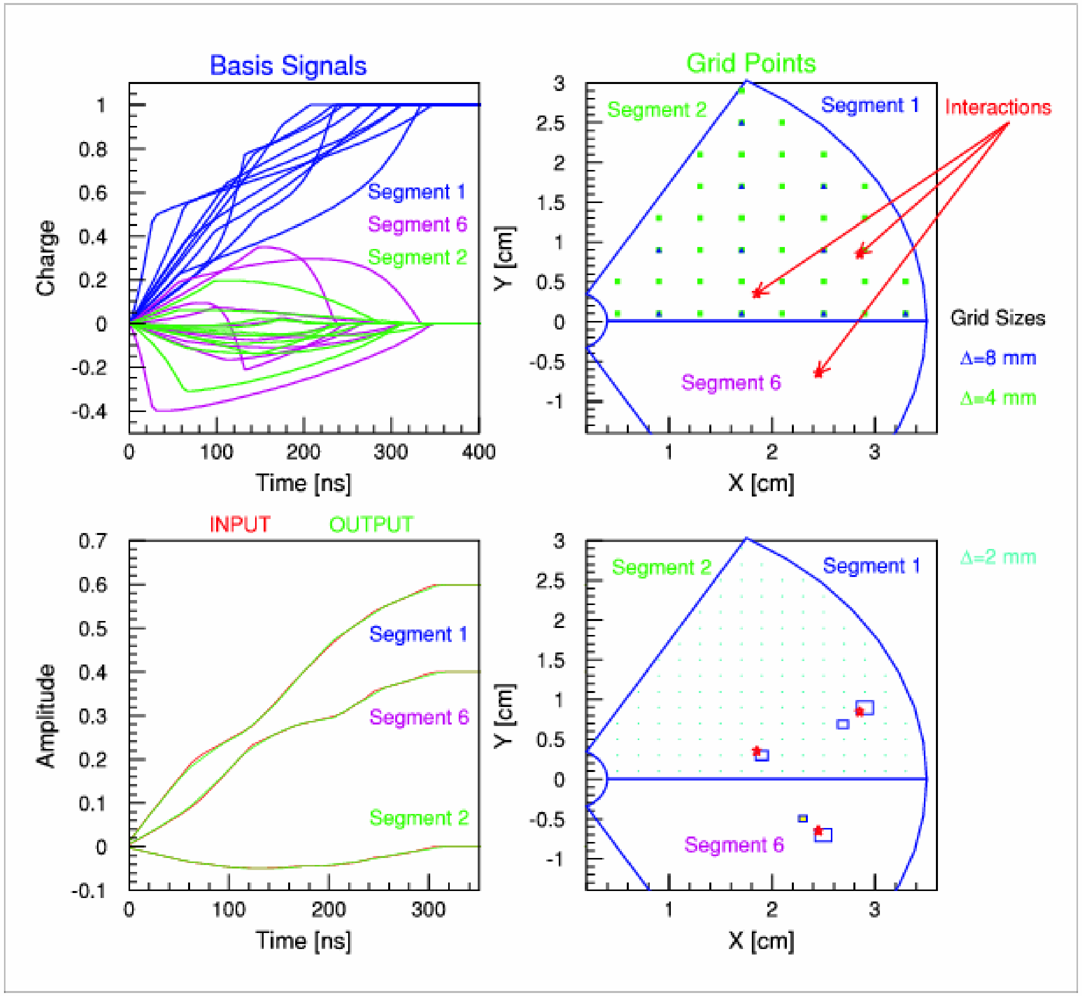
- **Good energy resolution: 2 keV for 1 MeV**
- **High sampling rate: 12bit, 100 MHz**
- **Large processing power: 10 Gflop**



Signal digitizer module

Signal decomposition

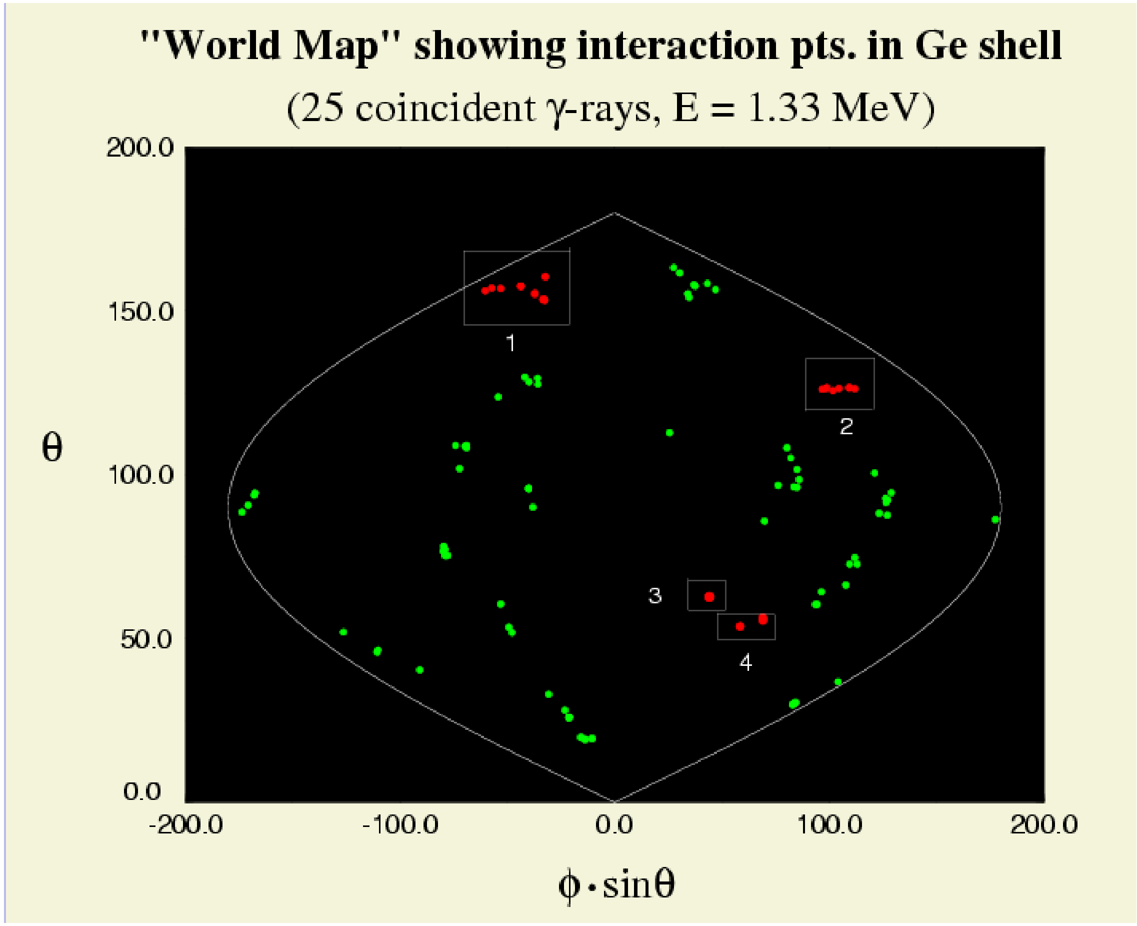
- Determine energy and position of multiple interactions in multiple segments
- The most Computational intensive task

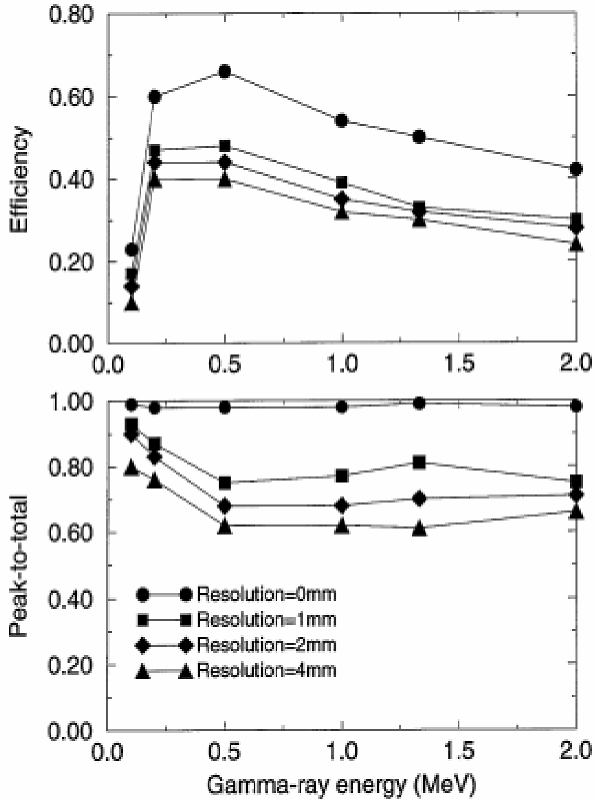


- Calculate signal in each segment for interactions on a grid ➔ base signals(10^6)
- Decompose the composite signal into a linear combination of base signals
- Interpolate to improve position resolution

Tracking of interaction points

- **Resolve multiple gamma rays in one event**
- **Staged approach: Cluster identification and tracking**





R&D Accomplishments

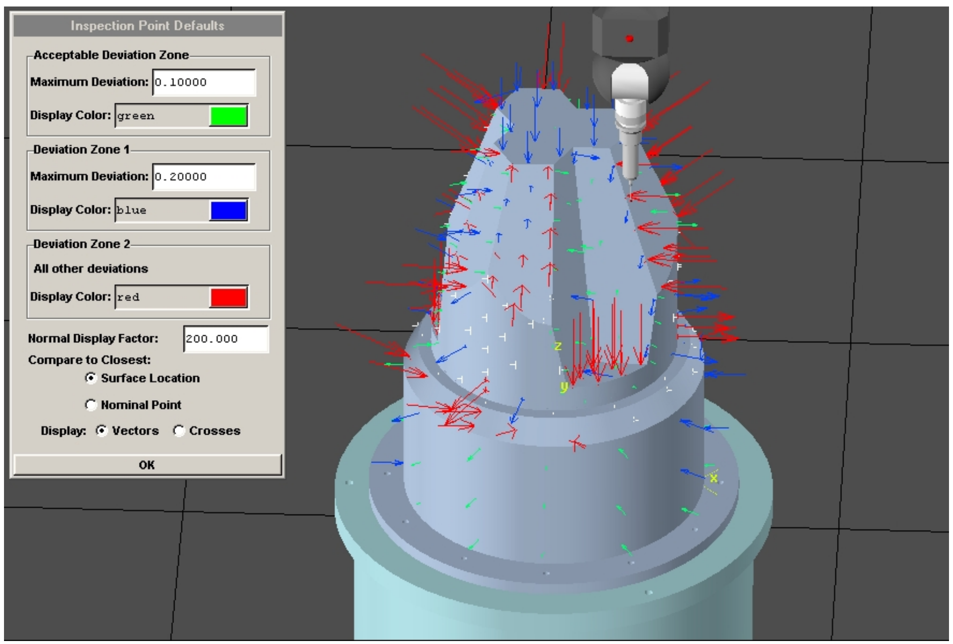
Prototyping (2001 – 2004)

- **Three-crystal detector module**
  - **Ordered 9/6/02, received 6/4/2004**
- **End-to-end data analysis**
  - **Analyzed both source data and simulated data**
  - **Measurements agreed with simulation**
- **In-beam test**
  - **Demonstrated a position resolution of 2.4 mm (RMS in 3D)**
- **Signal digitizer**
  - **20 Mark II 8-channel modules produced and in-use**
- **Data acquisition**
  - **Set up a VME based acquisition system for signal digitizer**
  - **Developed software for off-line analysis**

Mechanical Measurement

(CMM)

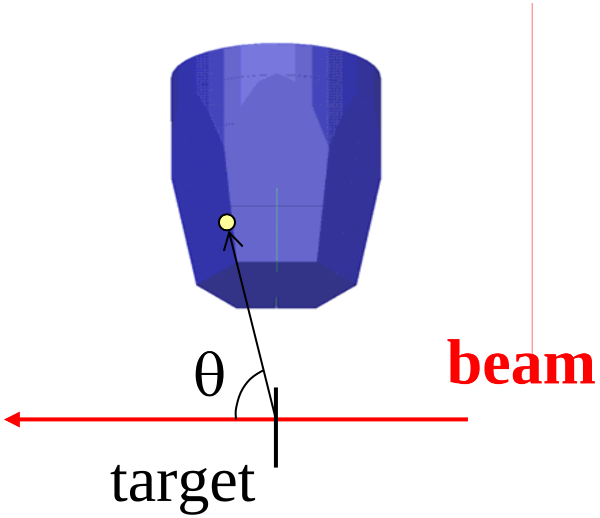
366 points measured
at room and liquid-nitrogen temperatures



Results:

- **Deviation from design value = 0.2 mm (RMS)**
- **Warm – cold difference = 0.02 mm (RMS)**

In-beam test



Experiment

- LBNL 88” Cyclotron (July 03)
- Prototype II detector
- ^{82}Se + ^{12}C @ 385 MeV
- ^{90}Zr nuclei (β ~ 8.9%)
- 2055 keV ($10^+ \rightarrow 8^+$) in ^{90}Zr
- Detector at 4 cm and 90°
- Three 8-channels LBNL signal Digitizer modules (24 ch.)

Analysis

- Event building
- Calibration : cross talk
- Signal decomposition
- Doppler correction

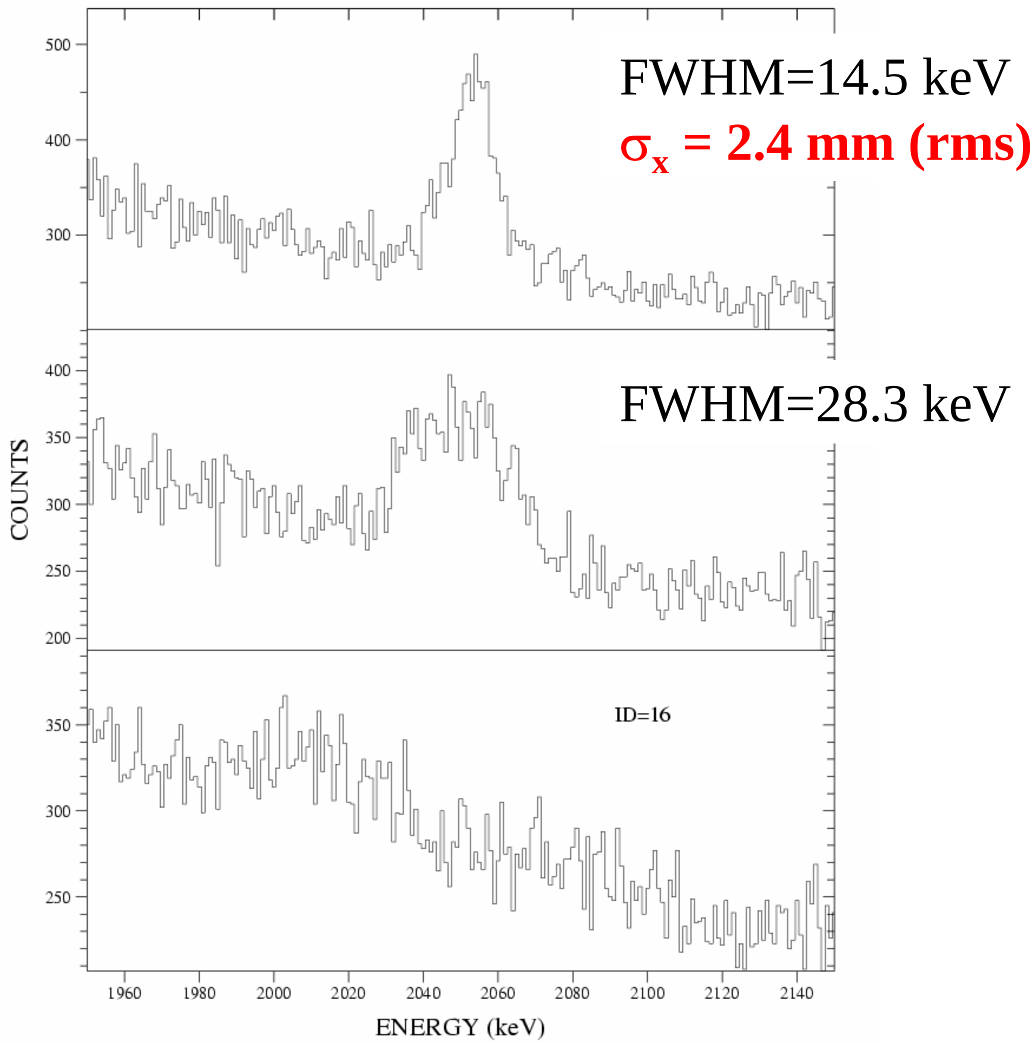
In-beam test Results

Sum all segments in layers 3 and 4, except segment E

Doppler Corrected using first hit position determined by signal decomposition

Corrected using center of segment only

No correction



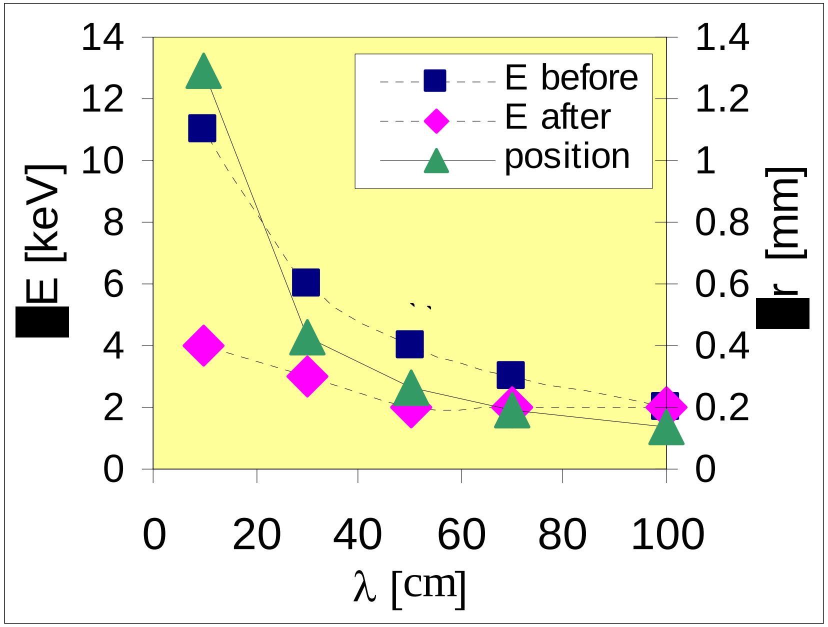
Neutron Damage Effects

- Pulse Shape have been calculated for different λ
- Energy and position resolution have been extracted
- Degradation in E & P resolution depends on hole path
- Energy is corrected for interaction position

- Neutron damage has more effect on energy than on position resolution
- The detectors needs to be annealed before the position resolution will be affected.

$(\lambda_c)_{\Delta E} \sim 30$ cm
$(\lambda_c)_{\Delta r} \sim 17$ cm

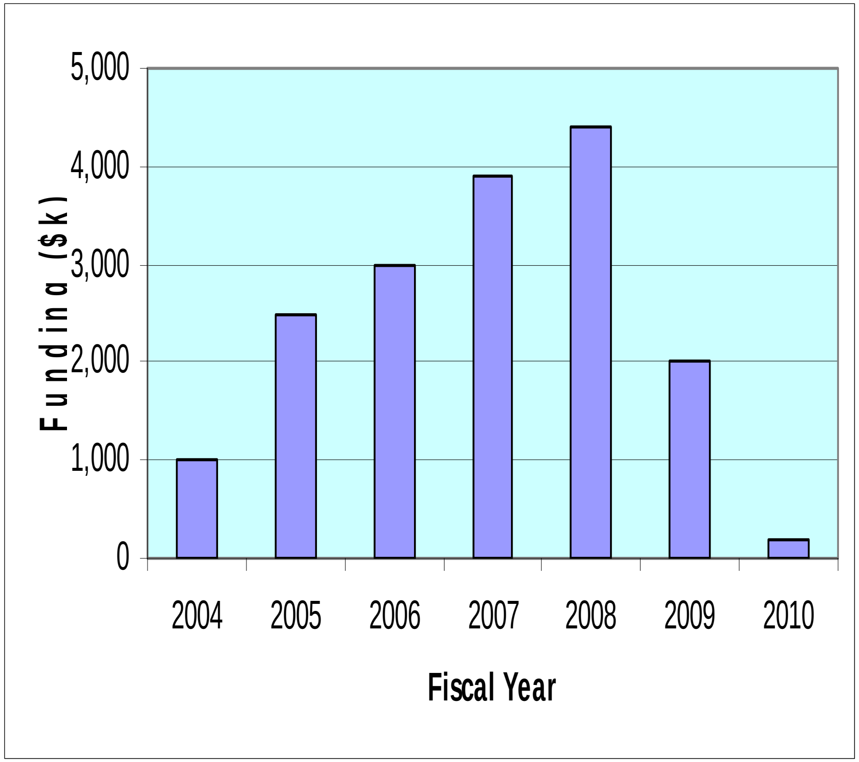
10 keV ~ 1 mm



GRETINA Cost *(Jan. 04)*

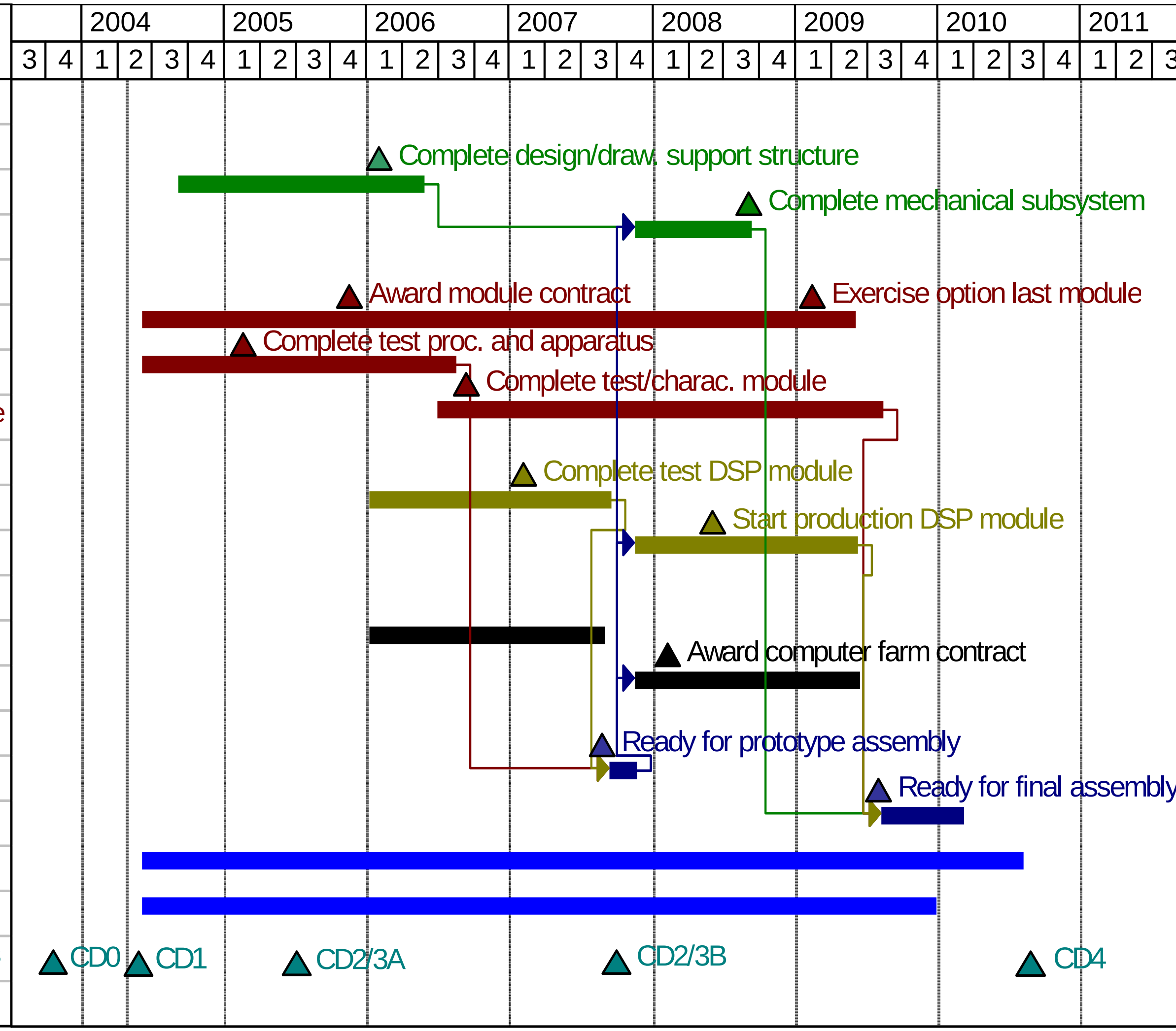
Item	Cost (M$)
• Mechanical	0.91
• Detector	6.95
• Electronics	1.52
• Computer	1.15
• Assembly	0.18
• Management	2.22
• Safety	0.12
Sub total	13.05
Contingency	2.85 (22%)
Escalation	1.10
Total (TEC)	**17.0**

Includes overhead
Does not include R&D and scientific efforts



GRETINA Schedule (Fiscal Years)

WBS	Task Name
1	GRETINA
1.1	Mechanical
1.1.2	Design
1.1.3	Production
1.2	Detector Module
1.2.1	Purchasing
1.2.2	Test/Characterize Module 1
1.2.3	Test/Characterize Rest of Module
1.3	Electronics
1.3.2	Prototype
1.3.3	Production
1.4	Computing Systems
1.4.2	Prototype
1.4.3	Production
1.5	System Assembly
1.5.1	Prototype
1.5.2	Production
1.6	Project Management
1.7	Environment and Safety
1.12	Level 1 Milestones: Critical Decisions



Plan in 2004 - 2005

- **Define requirements of subsystems**
- **Install 120 digitizer channels (15 modules)**
- **Test 3-crystal detector module**
- **Study detector design : 4 vs. 3 crystal / cryostat, and warm vs. cold FETs**
- **Develop trigger/timing module and algorithm**
- **Develop prototype acquisition system**
- **Improve signal decomposition and tracking algorithms**

Collaborating Institutions

Role defined by MOU's

Draft of MOU's received from

- **Argonne National Laboratory**
  - Trigger system
  - Calibration and online monitoring software
- **Michigan State University**
  - Detector testing
- **Oak Ridge National Laboratory**
  - Liquid nitrogen supply system
  - Data acquisition
- **Washington University**
  - Target chamber

Gretina Advisory Committee

- Con Beausang, *Yale University*
- Doug Cline, *University of Rochester*
- Thomas Glasmacher, *Michigan State University*
- C. Kim Lister, *Argonne National Laboratory*
- Augusto Macchiavelli, *Lawrence Berkeley Laboratory*
- David Radford(Chair), *Oak Ridge National Laboratory*
- Mark Riley, *Florida State University*
- Demetrios Sarantites, *Washington University*
- Kai Vetter, *Lawrence Livermore National Laboratory*

http://radware.phy.ornl.gov/greta/news3/

Working Groups

- Physics M. A. Riley
- Detector A. O. Macchiavelli
- Electronics D. C. Radford
- Software M. Cromaz
- Auxiliary Detectors D. G. Sarantites

ANL, LANL, LBNL, LLNL, NRL, ORNL
FSU, Georgia Tech, MSU, Purdue, U. Mass. Lowell,
Rochester, Notre Dame, Vanderbilt, Wash. U., Yale

Working Group Meetings

- **Detector**
  – March 19-20, 2004, ORNL
- **Software**
  – June 22-23, 2004, LBNL
  – Dec. 04, ?
- **Electronics**
  – July 24-25, 2004, ANL

Summary

- GRETINA, π array, project has started
- Estimated cost is $17M
- Completion date is 2010
- Early implementation experiments possible starting 2006
- First step toward a 4π array, GRETA, for RIA